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THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF BITUMINOUS PAVING MIXTURES

CAUTION: Prior to handling test materials, performing equipment setups, and/or conducting this method, testers are required to read **"SAFETY AND HEALTH"** in Section M of this method. It is the responsibility of the user of this method to consult and use departmental safety and health practices and determine the applicability of regulatory limitations before any testing is performed.

A. SCOPE

This method of test is a modification of AASHTO Designation T 209 that covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25°C.

NOTE 1**:** The precision of the method is best when the procedure is run on samples that contain aggregates that are completely coated. In order to assure complete coating it is desirable to run the method on samples that are close to the optimum asphalt content.

B. TERMINOLOGY

The terms specific gravity and density used in this test method are in accordance with AASHTO Designation M 132.

Definitions:

1. Density: as determined by this test method, is the mass of a cubic meter of the material at 25°C.
2. Residual pressure: as employed by this test method, is the pressure in a vacuum vessel when vacuum is applied.
3. Specific gravity: as determined by this test method, is the ratio of a given mass of material at 25°C to the mass of an equal volume of water at the same temperature.

C. SUMMARY OF TEST METHOD

A weighed sample of oven-dry paving mixture in the loose condition is placed in a tared vacuum vessel. Sufficient water at a temperature of 25 ± 4°C is added to completely submerge the sample. Vacuum is applied for 15 ± 2 mins. to gradually reduce the residual pressure in the vacuum vessel to 3.7 ± 0.3 kPa (28 ± 2 mm Hg). At the end of the vacuum period, the vacuum is gradually released. The volume of the sample of paving mixture is obtained by (Section H.5.a) filling the vacuum container full of water and weighing in air. At the time of weighing the temperature is measured as well as the mass. From the mass and volume measurements, the specific gravity or density at 25°C is calculated. If the temperature employed is different from 25°C, an appropriate correction is applied according to the method shown in the Appendix.

D. SIGNIFICANCE AND USE

The theoretical maximum specific gravities and densities of bituminous paving mixtures are intrinsic properties whose values are influenced by the composition of the mixtures in terms of types and amounts of aggregates and bituminous materials.

1. They are used to calculate values for percent air voids in compacted bituminous paving mixtures.

2. They provide target values for the compaction of bituminous paving mixtures.

3. They are essential when calculating the amount of bitumen absorbed by the internal porosity of the individual aggregate particles in a bituminous paving mixture.

E. APPARATUS

Vacuum Container:

1. Two different vacuum containers are described. Each must be capable of withstanding the full vacuum applied, and each must be equipped with the fittings and other accessories required by the test procedure being employed. The opening in the container leading to the vacuum pump shall be covered by a piece of 75 µm wire mesh to minimize the loss of fine material.

2. The vacuum container size depends on the minimum sample size requirements given in Section F.2. Avoid using a small sample in a large container.

3. Vacuum containers for weighing in air only.

    a. Type D – An intermediate size heavy-wall glass pycnometer with a capacity of approximately 4000 mL.

    b. Type E – A 4500 mL metal vacuum pycnometer with a clear polymethyl methacrylate (PMMA) lid.

Balance with capacity of 10 000 g, and capable of measuring the mass of the pycnometer filled with sample and water to an accuracy of 0.1 g to enable the specific gravity of samples of uncompacted paving mixtures to be calculated to at least four significant figures; that is, to at least three decimal places.

Vacuum pump capable of evacuating air from the vacuum container to a residual pressure of 3.7 ± 0.3 kPa (28 ± 2 mm Hg).

NOTE 2: A suitable trap of one or more 1000 mL filter flasks, or equivalent, shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.

Residual Pressure Manometer to be connected directly to the vacuum vessel and to be capable of measuring residual pressure down to 3.4 kPa (26 mm Hg) or less (preferably to zero). It is to be connected at the end of the vacuum line using an appropriate tube and either a "T" connector on top of the vessel or by using a separate opening (from the vacuum line) in the top of the vessel to attach the hose. To avoid damage, the manometer itself is not to be situated on top of the vessel but adjacent to it.

NOTE 3: A residual pressure of 4.0 kPa (30 mm Hg) absolute pressure is approximately equivalent to 97 kPa (730 mm Hg) reading on a vacuum gauge at sea level.

NOTE 4: Residual pressure in the vacuum vessel measured in millimeters of mercury, is the difference in the height of mercury in the Torricellian vacuum leg of the manometer and the height of mercury in the other leg of the manometer that is attached to the vacuum vessel.

Vacuum Gauge suitable for measuring the vacuum being applied at the source of the vacuum line. This is required to check the reading given by the residual pressure manometer attached directly to the vacuum vessel.

NOTE 5: The Torricellian vacuum leg of the manometer occasionally acquires one or more bubbles of air that introduce error into the residual pressure reading. By the addition of the vacuum gauge this error can often be quickly detected by the differences between two vacuum measurements.

Thermometers calibrated liquid-in-glass thermometers of suitable range with subdivisions and maximum scale error of 0.5°C, or any other thermometric device of equal accuracy, precision and sensitivity shall be used. Thermometers shall conform to the requirements of ASTM Specification E 1.

Bleeder Valve attached to the vacuum train to facilitate adjustment of the vacuum being applied to the vacuum vessel.

Protective Gloves used when handling glass equipment under vacuum.

NOTE 6: An example of a correct arrangement of the testing equipment is shown in Figure 1.

F. SAMPLING

1. Obtain the sample in accordance with California Test 125.

2. The size of the sample shall conform to the following requirements. Samples larger than the capacity of the container may be tested a portion at a time.

Size of Largest Particle of Aggregate in Mixture, mm	Minimum Sample Size, g
50.0	6000
37.5	4000
25.0	2500
19.0	2000
12.5	1500
9.5	1000
4.75	500

G. CALIBRATION OF FLASKS, BOWLS, AND PYCNOMETERS

1. Calibrate the Types D or E containers by determining the mass of the container when filled with water over the range of water temperatures likely to be encountered in service (Figure 2). Accurate filling may be ensured by the use of a glass cover plate. However, the mass of the glass cover plate should not be included in the mass of the pycnometer filled with water (Figure 2). Wipe the outside of the pycnometer dry, weigh the full pycnometer and glass cover plate, if used, and measure and record the temperature of the water. When calibrated at 25 ± 0.5°C, designate the mass of the pycnometer filled with water as *D* on the Calculation Sheet (Figure 5).

NOTE 7: The shape of the calibration curve is a function of two opposing factors that can be rationally defined. As the temperature is increased, the container itself expands and the density of the contained water decreases.

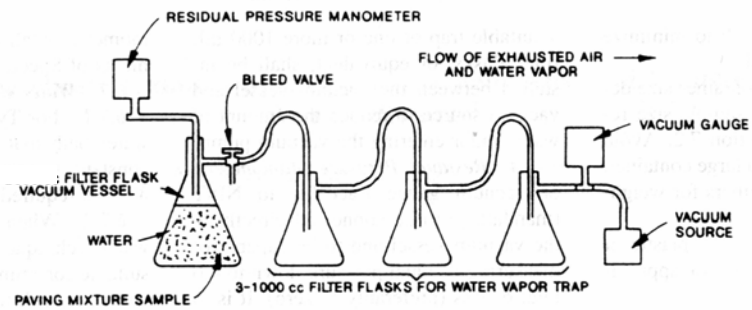

FIGURE 1 An example of the correct arrangement of testing apparatus (Note— The purpose of the train of small filter flasks is to trap water vapor from the vacuum vessel, that otherwise would enter the oil in the vacuum pump and decrease the pump's ability to provide high vacuum.)

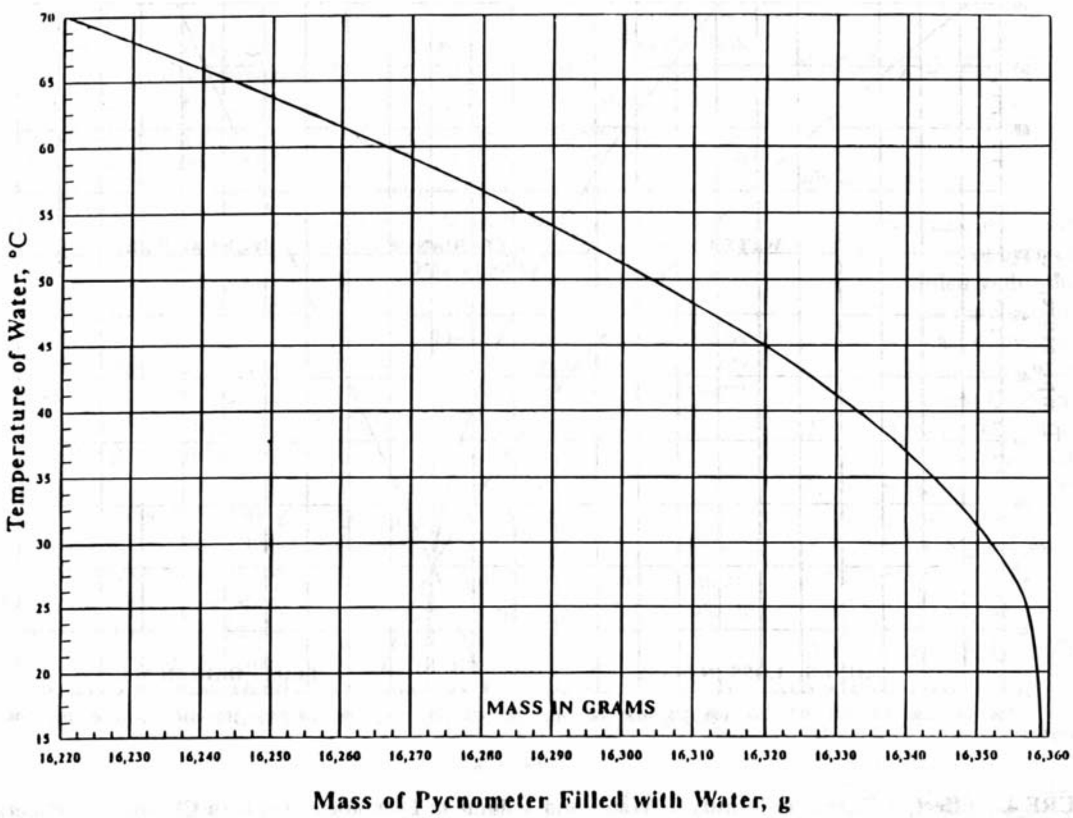

FIGURE 2. Example Calibration Curve for Pycnometer (D)

The "water" curve may be constructed by multiplying the volume at 25°C by the difference in density of water at 25°C, which is 0.9970 Mg/m^3, and at the calibration temperature.

Difference due to water expansion =
V_{25} (0.9970 – dw)

Since $V_{25} = W_{25}/0.9970$,
V_{25}(0.9970 – dw) reduces to:
W_{25}=(1-dw/0.9970)

Where:

V_{25} = volume of water to fill container at 25°C, cm^3,
W_{25} = mass of water to fill container at 25°C, g, and
dw = density of water at calibration temperature, Mg/m^3.

The rate of change in capacity of container due to thermal expansion of the pycnometer itself is essentially constant over the temperature range from 20 to 65°C. Thus, the pycnometer line can be drawn through the 0 at 25°C point knowing only the slope of the straight-line relationship. The slope can be established by averaging at least five calibration weighings at some elevated temperature, adding the loss due to water expansion and subtracting the mass at 25°C, W_{25}, to give the gain in capacity due to expansion of the container. The difference in mass divided by the difference in temperature is the slope of the pycnometer line. The bending of the calibration curve (Figure 2) due to these offsetting thermal factors thus minimizes experimental error due to temperature effects in the normal working range, 25°C, for pycnometer containers Types D and E. Defining the calibration curve makes it possible to correct for temperature.

2. While calibration of either pycnometer Types D or E need be done only once a year, the calibration should be checked occasionally, particularly at 25°C.

3. The equipment must be kept clean and free from any accumulation that would change the mass if the volume calibration is to remain constant. Care should be taken to use only neutral solvents. Glass vessels should not be subjected to high vacuum if they are scratched or damaged.

H. PROCEDURE

1. Separate the particles of the sample of paving mixture by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than 6.3 mm. If a sample of paving mixture is not sufficiently soft to be separated manually, place it in a flat pan, and warm it in an oven until it can be separated as described.

2. Samples prepared in a laboratory shall be cured and dried in an oven at 135 ± 5°C for a minimum of 2 hrs. Longer drying time may be necessary for the sample to achieve a constant mass (i.e., mass repeats within 0.1 %). Paving mixtures which have not been prepared in a laboratory with oven-dried aggregates shall be dried to a constant mass at a temperature of 105 ± 5°C. This drying and curing shall be combined with any warming described in Section H.1.

NOTE 8: The minimum 2 hr time in the oven is specified as cure time for laboratory-prepared specimens. The curing at the specified temperature is especially important when absorptive aggregates are used. This will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced materials should not be cured since absorption takes place during production.

3. Cool the sample to room temperature and place it in a tared calibrated pycnometer. The sample is to be placed directly into a Type D or E vacuum container. A container within a container is not to be used. Weigh and designate the net mass of the sample as A on the Calculation Sheet (Figure 5). Add sufficient water at a temperature of approximately 25°C to cover the sample completely.

4. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (28 ± 2 mm Hg). Maintain this residual pressure for 15 ± 2 mins. Agitate the container and contents during the vacuum period continuously using a mechanical device.

NOTE 9: The release of entrapped air may be facilitated by the addition of a suitable wetting agent such as Aerosol OT in concentration of 0.001 % or 0.2 g in 20 L of water. This solution is then diluted by about 20:1 to make a wetting agent of which 5 to 10 mL may be added to the apparatus.

5. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa per second and proceed with the following:

   a. Weighing in Air – Fill the pycnometers (Types D or E) with water and adjust the contents to a temperature of 25 ± 1°C.

   b. Determine the mass of the container (and contents), completely filled, in accordance with Section G.1 within 10 ± 1 mins after completing Section H.4. Designate this mass as E.

NOTE 10: See Appendix for correcting the theoretical maximum specific gravity when measurements are made at temperatures other than 25°C.

I. CALCULATION

1. Calculate the theoretical maximum specific gravity of the sample at 25°C as follows:

   a. Weighing in Air:

      Theoretical Maximum Specific Gravity =

$$\frac{A}{A+D-E} \qquad (1)$$

      Where:

      A = mass of oven dry sample in air, g
      D = mass of container filled with water at 25°C, g, and
      E = mass of container filled with sample and water at 25°C, g.

   b. If the test temperature is within + 1.7 or − 2.8°C of 25°C, that is, between 22.2 and 26.7°C, Equation 1 may be used to calculate specific gravity within 0.001 points or less error due to thermal effects.

      1) If the test temperature is less than 22.2°C or greater than 26.7°C, correct for thermal effects as follows:

         Theoretical Maximum Specific Gravity =

$$\frac{A}{(A+F)-(G+H)} \times \frac{dw}{0.9970} \qquad (2)$$

         Where:

         A = mass of dry sample in air, g,
         F = mass of pycnometer filled with water at test temperature, g,
         G = mass of pycnometer filled with water and sample at test temperature, g,

H = correction for thermal expansion of bitumen (Figure 3), g,
dw = density of water at test temperature. Curve D in Figure 4, Mg/m^3, and
0.9970 = density of water at 25°C, Mg/m^3.

The ratio (dw/0.9970) is Curve R in Figure 4.

c. When it is necessary to test a sample a portion at a time, the differences between the maximum specific gravities for each portion should be within the precision statements listed in Section L. If the values are within the precision statements, the specific gravities for each portion shall be averaged. If the values are outside the precision statements, the test shall be run again.

2. Calculate the corresponding theoretical maximum density at 25°C as follows:

   Theoretical maximum density at 25°C = theoretical maximum specific gravity x 997.0 kg/m^3.

   Where:

   Density of water at 25°C = 997.0 kg/m^3.

J. SUPPLEMENTAL PROCEDURE FOR MIXTURES CONTAINING POROUS AGGREGATE

Experiments indicate that this supplemental procedure has an insignificant effect on the test results if the mixture contains individual aggregate with water absorption below 1.5 %.

1. If the pores of the aggregates are not thoroughly sealed by a bituminous film, they may become saturated with water during the evacuation procedure. To determine if this has occurred, proceed as follows after completing the procedure in accordance with Section H.5.a. Drain water from the sample. To prevent loss of fine particles, decant water through a towel held over the top of the container. Break several large pieces of aggregate and examine the broken surfaces for wetness.

2. If the aggregate has absorbed water, spread the sample before an electric fan to remove surface moisture. Weigh at 15 min intervals, and when the loss in mass is less than 0.05 % for this interval, the sample may be considered to be surface dry. This procedure requires about 2 hrs and shall be accompanied by intermittent stirring of the sample. Break conglomerations of mixture by hand. Take care to prevent loss of particles of mixture.

3. To calculate the specific gravity of the sample, substitute the final surface-dry mass for A in the denominator of Equation 1 (Section I.1.a.)

K. REPORT

Report the following information:

1. Specific gravity and density of the mixture to the third decimal place as: specific gravity at 25°C or density at 25°C
2. Type of mixture
3. Size of sample
4. Number of samples
5. Type of container

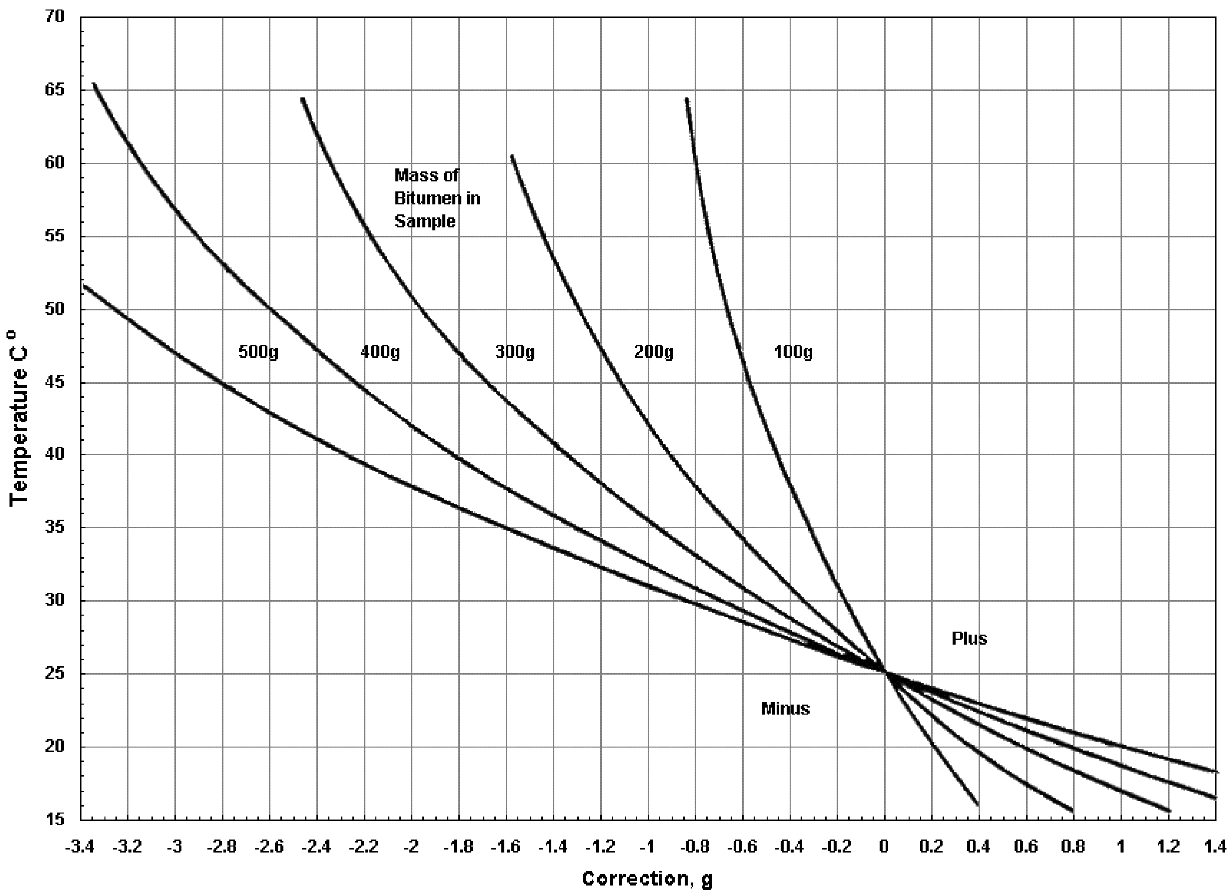

FIGURE 3. Correction Curves for Expansion of Bitumen, H, in Equation 2

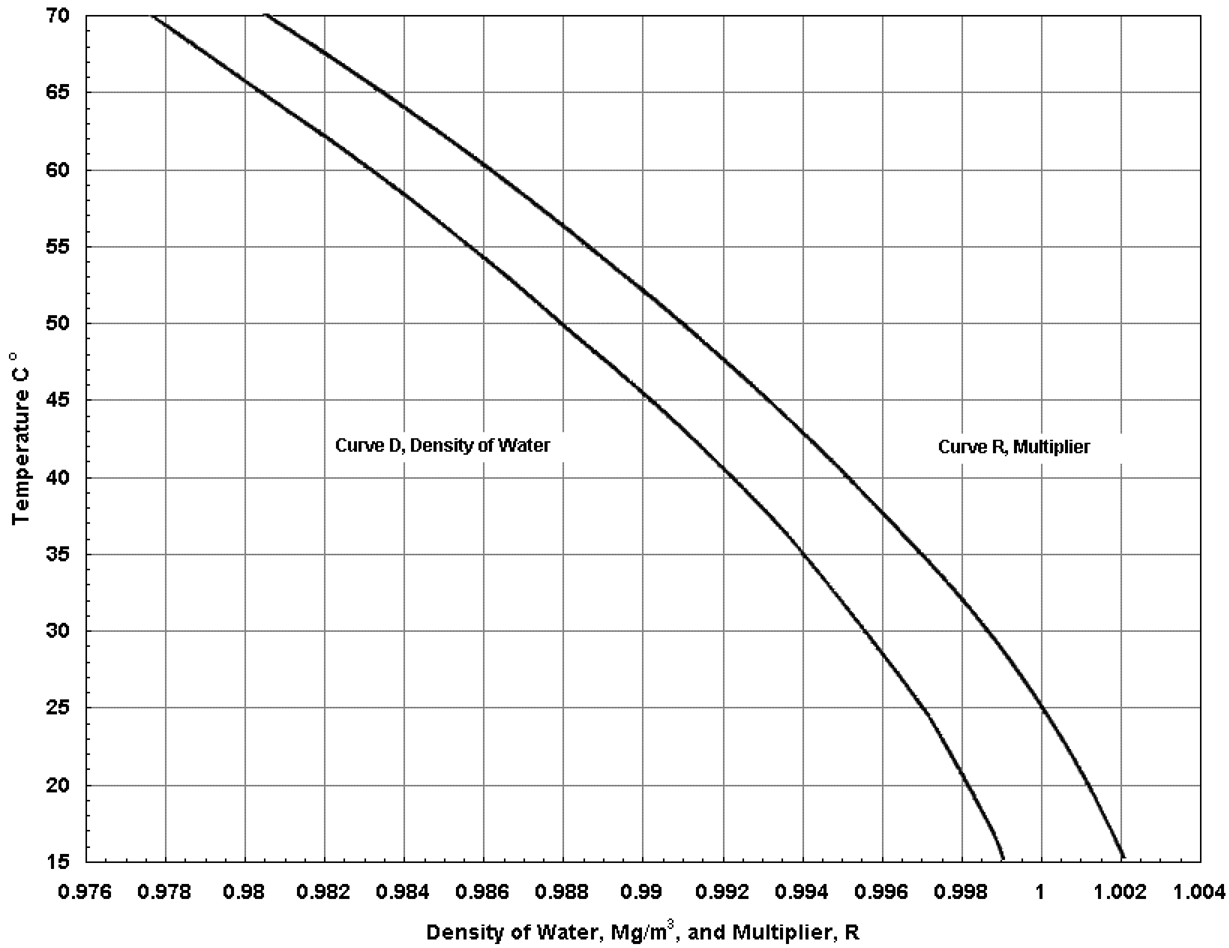

FIGURE 4. Curves D and R for Equation 2

L. PRECISION

1. Criteria for judging the acceptability of specific gravity test results obtained by this test method are given in the following table:

Test and Type	Standard Deviation (1s)	Acceptable Range of Two Results (d2s)
Test results obtained without use of Section J[A]		
Single-operator precision	0.0040	0.011
Multi-laboratory precision	0.0064	0.019
Test results obtained with use of Section J applicable for bowl determination only[B]		
Single-operator precision	0.0064	0.018
Multi-laboratory precision	0.0193	0.055

[A] Basis of estimate: 3 replicates, 5 materials, 5 laboratories.

[B] Basis of estimate: 2 replicates, 7 materials, 20 laboratories.

2. The figures given in Column 2 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. Multi-laboratory precision has not been verified for the 4500 mL pycnometer (Type E)

3. The values in Column 3 are the acceptable range for two tests. When more than two results are being evaluated, the range given in Column 3 must be increased. Multiply the standard deviation(s) in Column 2 by the multiplier given in Table 1 of Practice ASTM C 670 for the number of actual tests.

   Example for 3 tests:
   0.020 X 3.3 = 0.066.

   Additional guidance and background is given in Practice ASTM C 670.

Table 1: Influence of Temperature Corrections to a Measured Volume at 20°C of a Given Mass of Loose Paving Mixture, to Provide the Required Theoretical Maximum Specific Gravity at 25°C.

Temperature °C	Volume Loose Mix at 20°C	Volume Correction For Temperature Change	Corrected Volume at 20°C, Loose Mix	Mass of Loose Mix	Specific Gravity, Loose Mix
Column 1	2	3	4=2+3	5	6=5/4
31	492.77	0.2046	492.975	1251.3	2.5383
30[A]	492.77	0.1860	492.956	1251.3	2.5384
29[A]	492.77	0.1674	492.937	1251.3	2.5385
28[A]	492.77	0.1488	492.919	1251.3	2.5386
27[A]	492.77	0.1302	492.900	1251.3	2.5386
26[A]	492.77	0.1116	492.882	1251.3	2.5387
25[A]	492.77	0.0930	492.863	1251.3	2.5388
24[A]	492.77	0.0744	492.844	1251.3	2.5389
23[A]	492.77	0.0558	492.826	1251.3	2.5390
22[A]	492.77	0.0372	492.807	1251.3	2.5391
21[A]	492.77	0.0186	492.789	1251.3	2.5392
20	492.77	0.0000	492.772	1251.3	2.5393
19	492.77	-0.0186	492.751	1251.3	2.5394

[A] Range of values of specific gravity of loose mix (column 6) less than 0.0005.

NOTE 11**:** Strictly speaking, the above table shows that the specific gravity for this particular mix, as measured at 20°C just fails to meet the corrected theoretical maximum specific gravity at 25°C, 2.5388 versus 2.5393, that is by 0.0005, and that a temperature correction would be required.

NOTE 12: If the measurement for volume had been made at 21°C, the table indicates that no temperature correction would have been necessary, because the measurement at 21°C would have satisfied the theoretical maximum specific gravity at 25°C, 2.5388 versus 2.5392, a difference of less than 0.0005.

M. SAFETY AND HEALTH

Personnel should use heat resistant gloves when working with hot materials. Use proper lifting techniques when handling bags of aggregate. Reasonable care should be exercised to avoid being burned by hot asphalt, aggregate or equipment.

Prior to sampling, handling materials or testing, Caltrans personnel are required to read Part A (Section 5.0), Part B (Section 5.0, 6.0 and 10.0) and Part C (Section 1.0) of Caltrans Laboratory Safety Manual and the Materials Safety Data Sheets (MSDS) for all materials used. Users of this method do so at their own risk.

REFERENCES
California Test 125
AASHTO Designations: M 132, T 209, R 10
ASTM Designations: D 4311, E 1

End of Text
(California Test 309 contains 13 Pages)

DETERMINATION OF THEORETICAL MAXIMUM SPECIFIC GRAVITY OF BITUMINOUS PAVING MIXTURES

CALCULATION SHEET

TEST NO. ____________________

A. Mass of dry sample in air, g ____________________

D. Mass of container and water in air, g ____________________

E. Mass of container, sample and water in air, g ____________________

***Maximum Specific Gravity $\frac{A}{A+D-E}$ ____________________

TEST NO. ____________________

A. Mass of dry sample in air, g ____________________

D. Mass of container and water in air, g ____________________

E. Mass of container, sample and water in air, g ____________________

***Maximum Specific Gravity $\frac{A}{A+D-E}$ ____________________

TEST NO. ____________________

A. Mass of dry sample in air, g ____________________

D. Mass of container and water in air, g ____________________

E. Mass of container, sample and water in air, g ____________________

***Maximum Specific Gravity $\frac{A}{A+D-E}$ ____________________

Date: ____________________ Operator: ____

***Theoretical Maximum Specific Gravity reported to third decimal place.

Figure 5

APPENDIX

Non-mandatory Information

A. THEORETICAL MAXIMUM SPECIFIC GRAVITY FOR A LOOSE-PAVING MIXTURE

1. This Appendix has two objectives:

   a. To indicate a method for correcting the theoretical maximum specific gravity to 25°C when measurements are made at temperatures other than 25°C; and,
   b. To indicate the range of temperature in °C above or below 25°C within which no temperature correction is required, because the measured theoretical maximum specific values are shown to be 0.0004 or less than the value for 25°C.

2. Indicated Values:

   The following are indicated for the theoretical maximum specific gravity of a loose-paving mixture:

   - Mass of loose-paving mixture = 1251.3 g
   - Volume of loose-paving mixture at 25°C = 492.77 mL
   - Asphalt content = 5.0 % of mass of total mix
   - Specific gravity of asphalt at 25°C = 1.029
   - Bulk specific gravity of aggregate = 2.714
   - Cubical coefficient of expansion of asphalt at 20°C (ASTM D 4311) = 6.2×10^{-4} mL/mL/°C
   - Cubical coefficient of expansion of aggregate at 20°C = 2.2×10^{-5} mL/mL/°C

3. Basis of Calculation for One Gram of Loose-Paving Mixture at 20°C

   a. Mass of asphalt = 0.05 g
   b. Volume of asphalt = 0.05 g/1.029 = 0.0486 mL
   c. Mass of aggregate = 0.95 g
   d. Volume of aggregate = .95/2.714 = 0.3500 mL
   e. Volume of asphalt plus aggregate in one gram of loose-paving mixture at 20°C = 0.0486 mL + 0.3500 mL = 0.3986 mL

4. Basis of Calculation for Volume Change of One Gram of Loose-Paving Mixture for One °C from 20°C:

   a. Volume change for asphalt
      = $6.2 \times 10^{-4} \times 0.0486$ mL
      = 0.3013×10^{-4} mL
      = 3.0130×10^{-5} mL
   b. Volume change for aggregate
      = $2.2 \times 10^{-5} \times 0.3500$ mL
      = 0.77×10^{-5} mL
   c. Volume change for one gram of loose paving mixture for one °C change in temperature from 20°C
      = $3.0130 \times 10^{-5} + 0.7700 \times 10^{-5}$
      = 3.7830×10^{-5} mL

5. Volume Correction:

   For a difference in water temperature of one °C above or below 20°C, a correction to the volume of water displaced by one gram of loose-paving mixture can be made by the following equation:

   Correction = $\Delta T \times K_T \times V_T$ mL (3)

   Where:

   ΔT = 1°C
   K_T = volume change for one gram of loose paving mixture for 1°C change in temperature above or below 20°C = 3.7830×10^{-5} mL
   V_T = volume of water for corresponding 1251.3 g mass of loose-paving mixture at test temperature of 20°C = 492.77 mL

   Substituting in equation 3 gives:

   Correction
   = $1 \times 3.7830 \times 10^{-5} \times 492.77$ mL
   = 0.01864 mL per gram at 20°C